TECHNICAL REPORT

M-1 HELMET SUSPENSION SYSTEM

by

Anthony C. [illegible]

Watson ? Co., Inc.
Hartford, Conn.

Contract No. DAAG17-70-C-0025

January 1971

General Equipment & Packaging
Laboratory

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UNCLASSIFIED
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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Welson & Co., Inc. Hartford, Connecticut	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

M-1 Helmet Suspension System

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5. AUTHOR(S) (First name, middle initial, last name)

Mirabella, Anthony C.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1971	39	4

8a. CONTRACT OR GRANT NO. DAAG17-70-C-0025 b. PROJECT NO. 16-0088-K159 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 72-22-GP 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Natick Laboratories Natick, Massachusetts 01760

13. ABSTRACT

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The concept known as the Hook and Pile Suspension System was selected for final design effort and subsequent fabrication of 50 production units. This concept uses hook and pile fabric as the closure and sizing device between two patterned suspension system elements. The design is adjustable to fit the full range of head sizes. The suspension mounts to the helmet liner by means of two acrylic plastic brackets. The complete suspension, including chin strap, is removable from the liner in one assembly.

Fifty production units have been fabricated and delivered for field evaluation at Aberdeen Proving Grounds, Maryland. The results of this evaluation are not included in this report.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Improvement	8					
Helmet Suspension Systems	9		2			
Closing			8			
Suspending			8			
Helmets			1			
Helmet liners			1			
Hook and pile			10			

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ANTHONY C. MIRABELLA

WELSON & CO., INC.
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FOREWORD

This report covers work conducted under U. S. Army Natick Laboratories Contract No. DAAG17-70-C-0025. The project was initiated as a design study to develop a suspension system for a 6-pound helmet, but was subsequently changed to a study for a system for the M-1 helmet.

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ABSTRACT

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Initial program effort concentrated on the definition of design requirements. An existing U. S. Air Force sizing system was selected for the fabrication of wooden head mockups for use during the study. Improvements in stability were judged most important. Analysis was conducted to evaluate projectile impact energies, and a new criteria for heavy object impact was proposed. Six design concepts were fabricated for U. S. Army Natick Laboratories review and selection of a final design concept.

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M-1 HELMET SUSPENSION SYSTEM

1. INTRODUCTION

The U. S. Army M-1 infantrymen's helmet is most likely the best military helmet in service in the world today. Comparative testing conducted with experimental helmets and suspension systems have concluded that the M-1 system ranks highest in comfort and stability of all those tested.

Even so, it is obvious to all those familiar with the M-1 helmet and suspension systems that improvements in design are necessary and are possible with today's technologies. The objective of the engineering study program described herein was to design and develop an improved suspension system for use within the M-1 helmet liner. The study required the fabrication of 50 final design prototypes for U. S. Army evaluation. The results of this evaluation are not included in this report.

This study program was conducted in five phases as follows:

Phase A - preparation of study plan

Phase B - establish design requirements

Phase C - develop design concepts

Phase D - fabricate prototypes for evaluation

Phase E - fabricate 50 production units

2. DESIGN REQUIREMENTS

1. GENERAL

The present M-1 helmet system consists of the outer steel shell, a laminated nylon helmet liner, a sling-type suspension webbing with removable sweatband, nape strap, and chin strap attached to the steel shell. The helmets made available for this study incorporate mounting studs in the liner to permit removal of the suspension system webbing. With this exception, the basic configuration is identical to the infantry helmets in use since World War II.

Table 1 provides a breakdown of the significant physical characteristics of the M-1 suspension system. The suspension system components listed weigh a total of 117 grams. The suspension is entirely fabricated from straight sections of 1-1/8-inch web material. The one-size configuration is intended to be adjustable to accommodate the complete range of head sizes. It is against this present suspension system as a baseline that this study was conducted.

TABLE 1

M-1 SUSPENSION PHYSICAL CHARACTERISTICS

Number of Separable Components		
vertical suspension		1
sweat band		1
sweat band attachment clips		6
nape strap		1
chin strap		2 (not removable from steel shell)
	TOTAL	11
Number of Adjustments		
vertical suspension		3
sweat band		
buckle		1
attachment clips		6
nape strap		3
chin strap		1
	TOTAL	14
Number of Mounting Points		
to steel shell		2
to liner		9
	TOTAL	11
Number of Metal Devices		
on chin strap		3
on vertical suspension		
buckles		3
mounting clips		6
mounting clip rivets		6
on sweat band		
buckle		1
attachment clips		6
on liner		
mounting studs		6
mounting stud rivets		6
nape strap buckles		3
nape strap buckle rivets		3
on steel shell		
chin strap mountings rings		2
	TOTAL	45

b. SIZING SYSTEM

An immediate requirement of the contract was to investigate head sizing systems and to fabricate three wooden head forms for sizing use during the conduct of the program.

Arrangements were made with Mr. Milton Alexander at Wright Patterson Air Force Base, Dayton, Ohio, to have the Air Force provide a set of six plaster head forms manufactured from master molds developed under an Air Force contract. References 1 and 2 describe the statistical anthropometric data and analyses used in creating the head forms. The key dimension in this sizing system is head circumference. Zeigen, in Reference 2, justifies head circumference as the sizing key over head length and breadth, by stating in part:

"Head length and breadth appear to be really critical only in entirely rigid helmets having no adjustability in the support; in liner, sling, or pad-type helmets, there is always some degree of adjustability, so that if head circumference is controlled, head breadth and length will also be readily accommodated as long as sufficient room is provided in the shell. Although head length and breadth may be thought to better represent head shape than head circumference, representative head shapes are still provided by headforms using the key dimension head circumference."

The six plaster head forms provided a three dimensional representation of the Air Force head sizing system. The intervals of head circumference represented by the head forms are:

Size	Head Circumference (in.)
1	21.0 - 21.5
2	21.5 - 22.0
3	22.0 - 22.5
4	22.5 - 23.0
5	23.0 - 23.5
6	23.5 - 24.0

Reference 2 explains that a three-size program can be used for design of helmets and suspension systems that include devices such as slings, pads, and spacers capable of adjustment. The three size program is accomplished by selecting the alternate (even) sizes (2, 4, and 6) of the six-size program. The resulting intervals of head circumference represented by the three selected head forms are:

Size	Head Circumference (in.)
2	21.0 - 22.0
4	22.0 - 23.0
6	23.0 - 24.0

Table 2, extracted from reference 2, presents the percentile coverage for the design ranges of the three-size program.

The three wooden head forms were hand sculptured out of laminated honduras mahogany blocks, using templates made from the plaster head forms. A photograph of the finished head forms is presented in Figure 1.

c. STABILITY

The three major instabilities which can occur are:

1) Pitch - Helmet motion relative to the head in a fore-aft direction.

2) Roll - Helmet motion relative to the head in side to side direction.

3) Yaw - Helmet motion relative to the head around the spinal axis.

There are essentially two design solutions available to correct instability. The first involves geometrical control to make the helmet suspension system aperture smaller than the maximum head dimension that the system must pass over in order to free itself. The nape strap is an example of a geometrical control solution. The second solution involves increasing the frictional forces between the head and the suspension system. A number of factors must be considered in this solution:

1) Materials in contact with hair and skin - maximize coefficient of friction.

2) Normal forces - maximize within comfortable levels.

3) Direction of suspension system straps - perpendicular to direction of motion.

Considering the case of helmet/head rotation about the neck pivot point in either the frontal or sagittal planes the importance of the foregoing factors can be shown.

TABLE 2

PERCENTILE COVERAGE FOR DESIGN RANGES OF THE THREE-SIZE MEAN PROGRAM

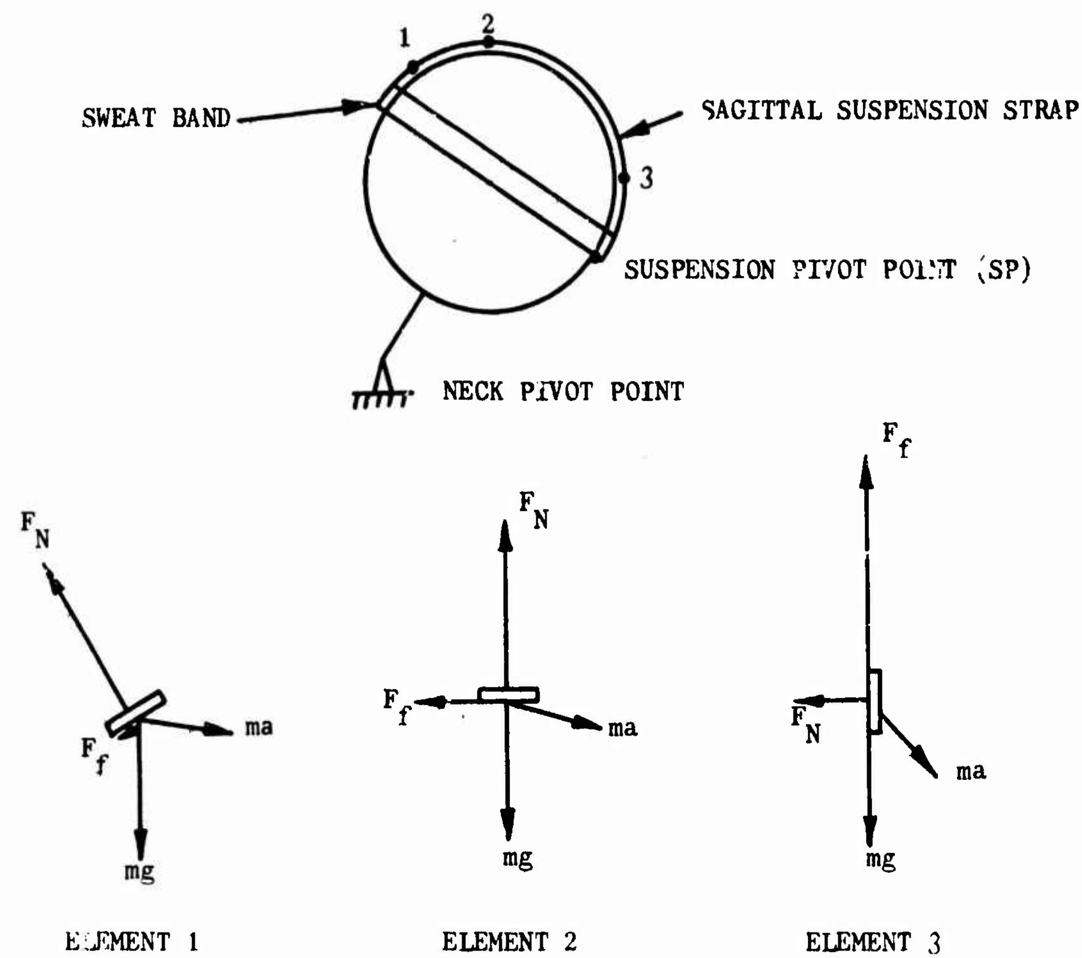
SIZE:		2 (Small)		4 (Medium)		6 (Large)	
DIMENSION:		MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
1.	Head circumference	1	20	20	80	80	98
2.	Head length	1	75	12	90	32	99
3.	Head breadth	2	75	10	91	20	98
4.	Minimum frontal diameter	2	85	5	93	15	98
5.	Maximum frontal diameter	2	90	5	95	15	97
6.	Bizygomatic diameter	3	80	8	93	25	98
7.	Bigonial diameter	3	90	8	95	10	98
8.	Bitragion diameter	2	85	5	95	15	98
9.	Biocular diameter	1	85	6	95	16	98
10.	Interocular diameter	2	85	6	92	17	97
11.	Ear length	2	92	5	96	9	96
12.	Ear breadth	3	94	3	94	9	97
13.	Ear length above tragion	6	95	6	95	6	95
14.	Ear protrusion	3	91	3	95	3	95
15.	Head height	2	90	8	95	12	98
16.	Menton projection	2	92	4	95	5	96
17.	External canthus to wall	2	85	8	92	12	98
18.	Nasal root to wall	1	82	8	92	25	99
19.	Tragion to wall	2	90	8	95	12	97
20.	Sagittal arc	2	78	8	95	20	98

TABLE 2 (CONT'D)

PERCENTILE COVERAGE FOR DESIGN RANGES OF THE THREE-SIZE MEAN PROGRAM

SIZE:	2 (Small)		4 (Medium)		6 (Large)	
DIMENSION:	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
21. Bitragion-coronal arc	2	86	8	94	15	98
22. Minimum frontal arc	2	92	5	97	9	98
23. Bitragion-minimum frontal arc	1	75	8	92	22	98
24. Bitragion-crinion arc	1	86	5	92	12	98
25. Bitragion-menton arc	2	88	8	94	18	98
26. Bitragion-submandibular arc	1	81	6	94	15	98
27. Bitragion-posterior arc	1	82	5	94	20	98
28. Bitragion-inion arc	1	82	5	91	15	98
29. Neck circumference	2	88	6	92	16	98

FIGURE 1 - WOOD HEAD FORMS



F_N - NORMAL FORCE ON ELEMENT

F_f - FRICTIONAL FORCE ON ELEMENT

m - ELEMENT MASS

a - ELEMENT ACCELERATION

FIGURE 2 - DECELERATION OF HEAD/HELMET ABOVE THE NECK PIVOT POINT

Figure 2 illustrates the condition of the head/helmet system decelerating to a rest condition from a motion about the neck pivot point. Assuming an equilibrium condition (no relative motion between the suspension and the head) the contribution of each strap of the suspension system to stability can be simply assessed. The suspension strap in the example of Figure 2 lies in the sagittal plane which is the plane of head motion for the example. Elements 1, 2, and 3 are representative of segments of the sagittal strap. The retaining frictional force F_f is greatest on forward portion of the strap and decreases to a minimum in the rear portion as shown by the force diagrams of each element. With an acceleration level (a) greater than that scaled in the diagram it can be seen that the frictional restraining force F_f disappears. The result is loosening and lifting of the strap from the head, followed by rotation of the suspension about point SP when the frictional forces in the sweatband have been exceeded.

A suspension strap has greater effectiveness when it is placed perpendicular to the direction of head motion as shown in Figure 3.

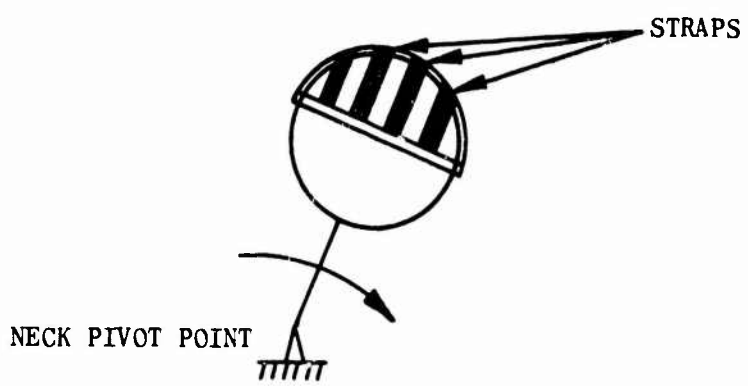


FIGURE 3 - STRAPS PERPENDICULAR TO DIRECTION OF MOTION

The forward straps can be designed to provide more uniform restraining forces over a greater area. The rear straps are still susceptible to lifting but to a lesser degree. For example, in Figure 2 the sagittal strap would lift first near the point of joining with the sweatband. The weight of the helmet would then help it peel forward and lift completely off the head. In the example of Figure 3, the strap would lift at the point furthest from the neck pivot point since this is the point of maximum acceleration. However, acceleration levels decrease along the strap towards the sweatband and the strap would remain in place provided increasing acceleration did not occur. The present M-1 suspension system uses two diagonally positioned and one sagittal plane "over the head" straps.

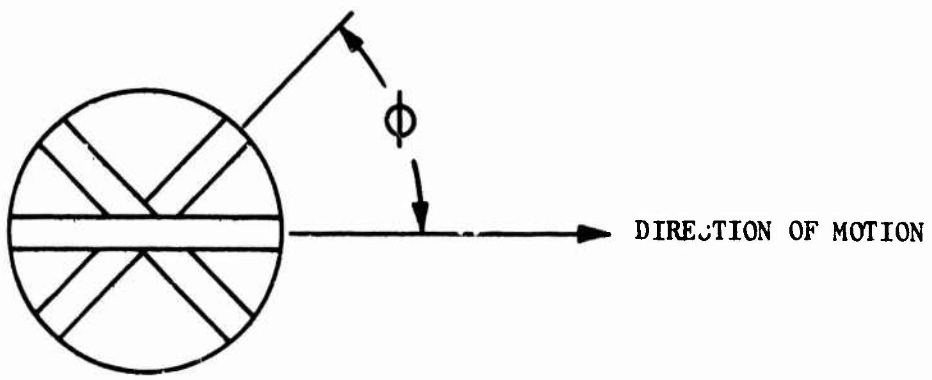


FIGURE 4 - STRAP ANGLE

The restraining force F_f is proportional to the angle between the direction of motion and the strap. The force F_f is a maximum when ϕ is 90^o and a minimum when ϕ is 0^o. Thus, in pitch and roll this design reduces the lift component on the diagonal straps (resulting in a greater F_f), but also reduces the restraining force in the sink side. The present M-1 system has a sagittal plane strap which is 90^o to roll motions. This helps explain why the present system performs better in roll than in pitch.

The chin strap provides a mechanical means of maintaining friction between the "over the head" straps and the head by means of inducing normal forces in the straps through tension. The chin strap can be attached to the helmet as it presently is, or to the suspension system. Chin strap tension is reduced by decreasing the angle between the helmet point of attachment and the chin and is accomplished by connecting the chin strap further inboard towards the head (as on the suspension system). A disadvantage of this method is that an alternative method of securing the steel shell to the liner is required.

Stability is also affected by head size, especially in this type of sizing system where one size helmet and liner accomodates all size heads. Stability becomes increasingly difficult to achieve in this system as the head size decreases.

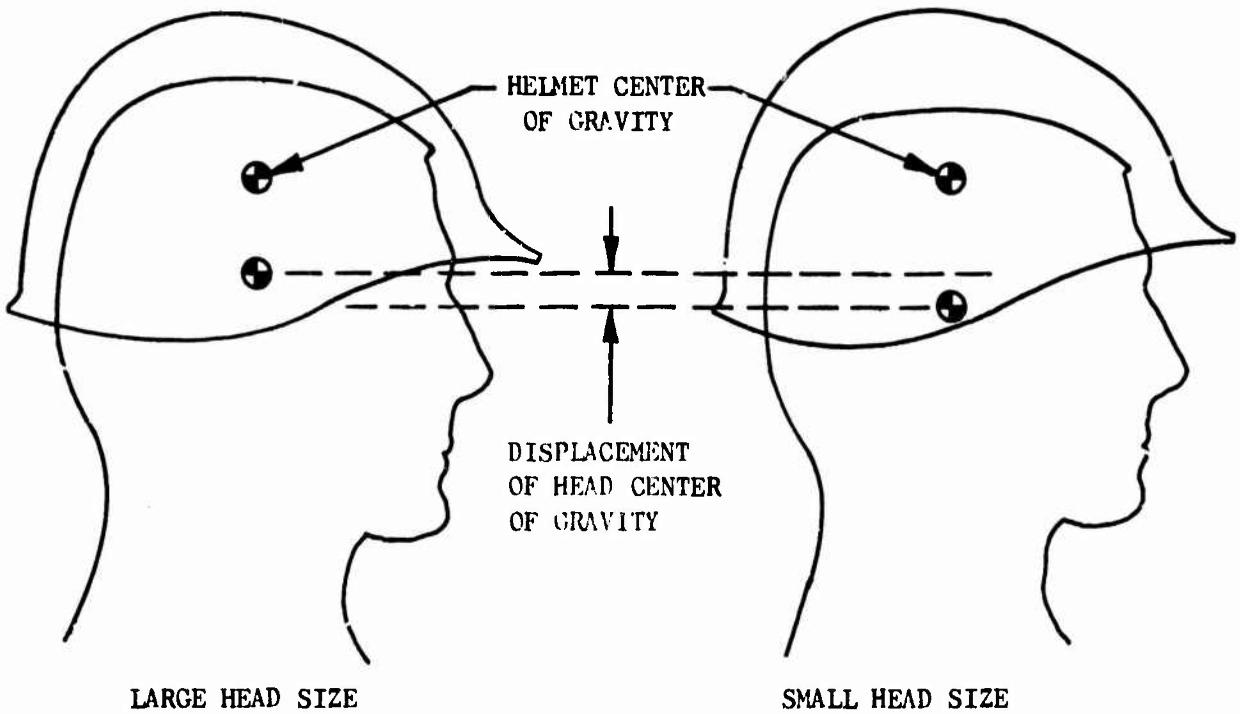


FIGURE 5 - LOCATIONS OF CENTERS OF GRAVITY

Figure 5 illustrates that the distance between the head and the helmet centers of gravity increases for smaller head sizes. The moment of inertia of the helmet/head system about the neck pivot point is a function of the distance to the c.g. squared; thus, small displacements of the helmet c.g. away from the head c.g. can greatly affect the dynamics of the helmet.

Smaller head sizes also result in an increased span between the sweatband and the mounting points of the suspension to the liner, as illustrated in Figure 6. This factor demands that the coupling suspension members be designed to resist bending to minimize relative motion between the suspension surfaces in contact with the head and the helmet.

Figure 7 helps illustrate the aforementioned factor and identifies another less obvious problem inherent with the present M-1 system. When worn on small size heads the present M-1 suspension system does not contact the head in the area between the top of the sweatband and the crown of the head. This phenomenon is caused by the location of the over-the-head strap mounting points. These straps

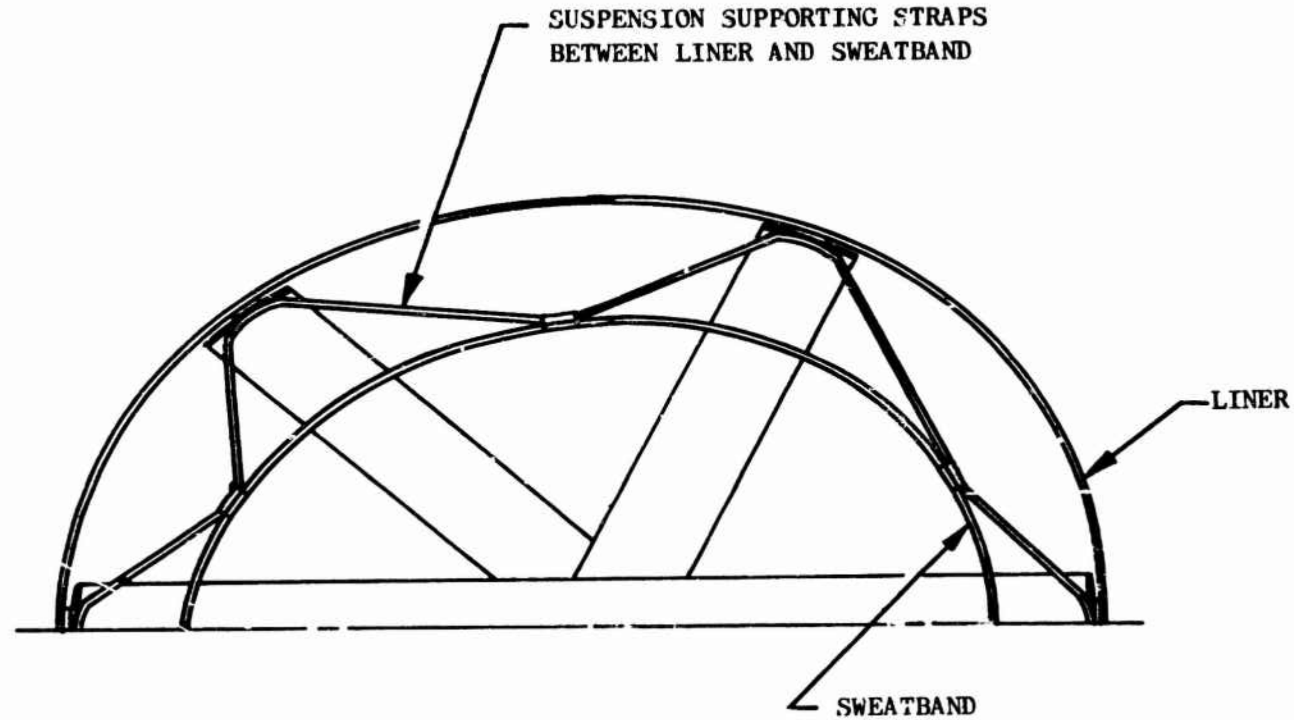


FIGURE 6 - SUSPENSION ADJUSTED FOR SMALL SIZE HEAD

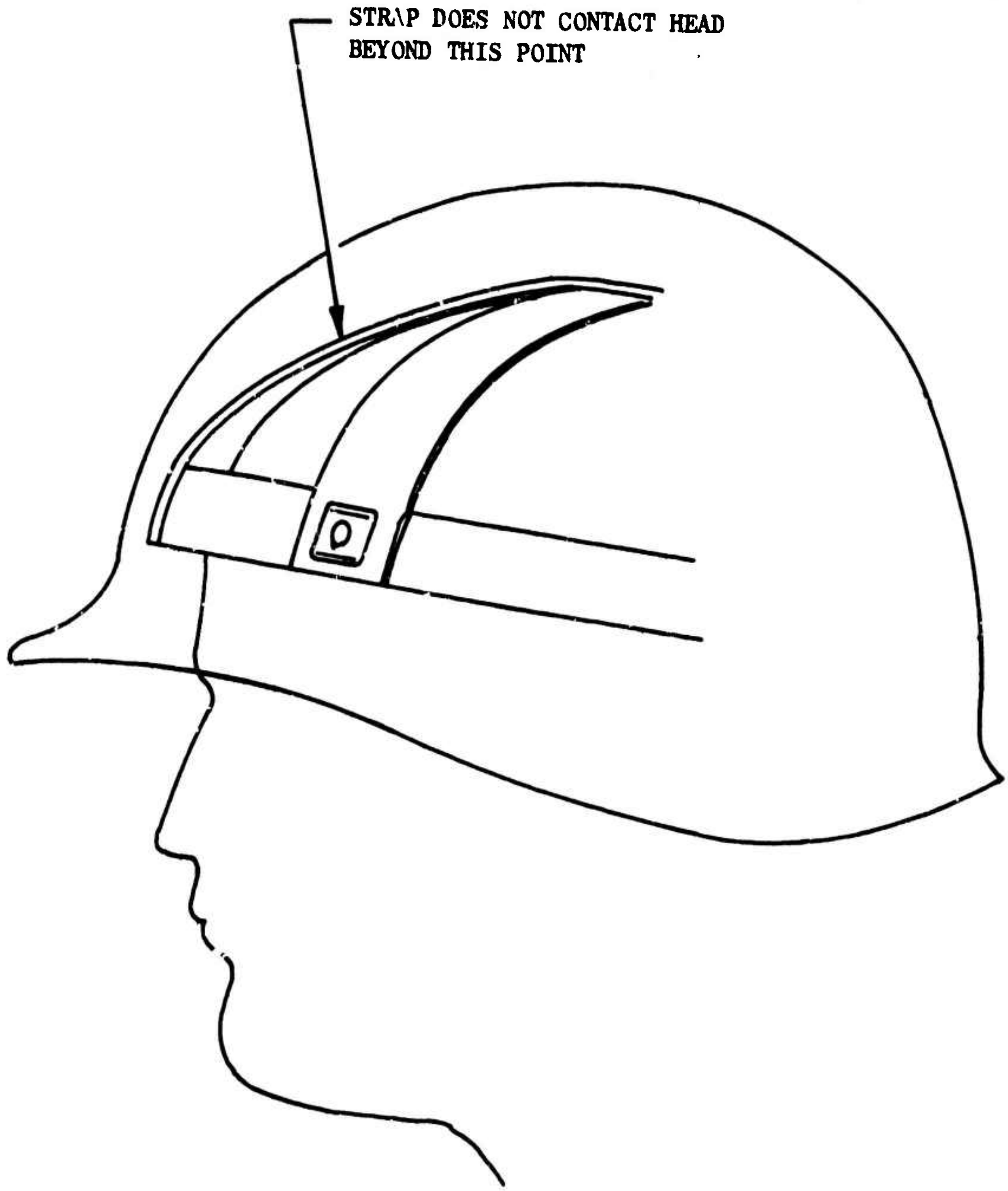


FIGURE 7 - ILLUSTRATION OF CONTACT PROBLEM BETWEEN SUSPENSION STRAPS AND SMALL SIZE HEAD

mount to the liner attachment points and not to the sweatband. Thus, the smaller the head, the greater the free span before the strap contacts the head. This factor results in instability through the reduction in contact area between the suspension and the head. It also causes the weight of the helmet to be concentrated over a smaller load carrying area and leads to more rapid discomfort.

d. IMPACT PROTECTION

The M-1 steel shell and liner is designed to give the soldier protection from impact by projectiles. The requirements imposed on the suspension system during this type of impact are:

1) The suspension system shall maintain sufficient offset of the helmet to provide protection against transient deformation.

   Figures 8 and 9 illustrate the clearances between the three size headforms and the interior surface of the helmet liner. Graphically it appears that adequate clearance (0.5 inches) can be obtained in all cases, with the exception of the large size (6HC) in the front to back direction. However, in actual practice, many men have been observed to wear the helmet lower to obtain better head coverage.

2) The suspension system design shall hold to a minimum the production of secondary missiles from suspension components when the helmet is penetrated by a projectile.

   Table 2 itemizes the metallic elements of the present suspension system which total the amazing number of 45. The objective of the study was to greatly reduce or eliminate the use of metallic devices in the suspension system design.

3) The suspension system design shall protect the neck and upper spinal cord.

   Neck and spinal cord injuries may result from the impact and pivoting of the rear of the helmet on the back of the neck. Protection against this whiplash effect is best achieved by bracing the helmet to the torso to prevent neck bending. Obviously this is not an acceptable

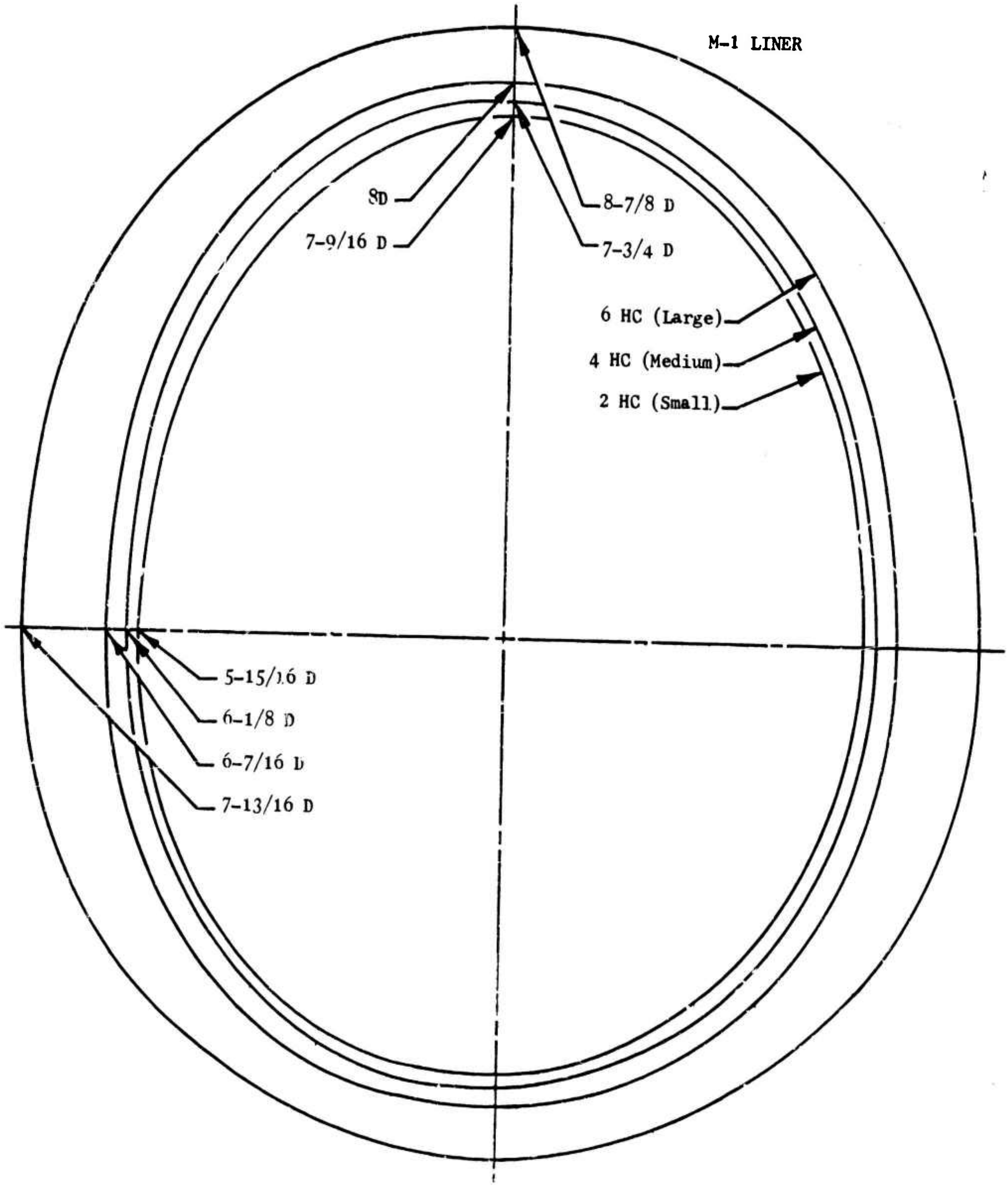


FIGURE 8 - LINER/HEADFORM CLEARANCES

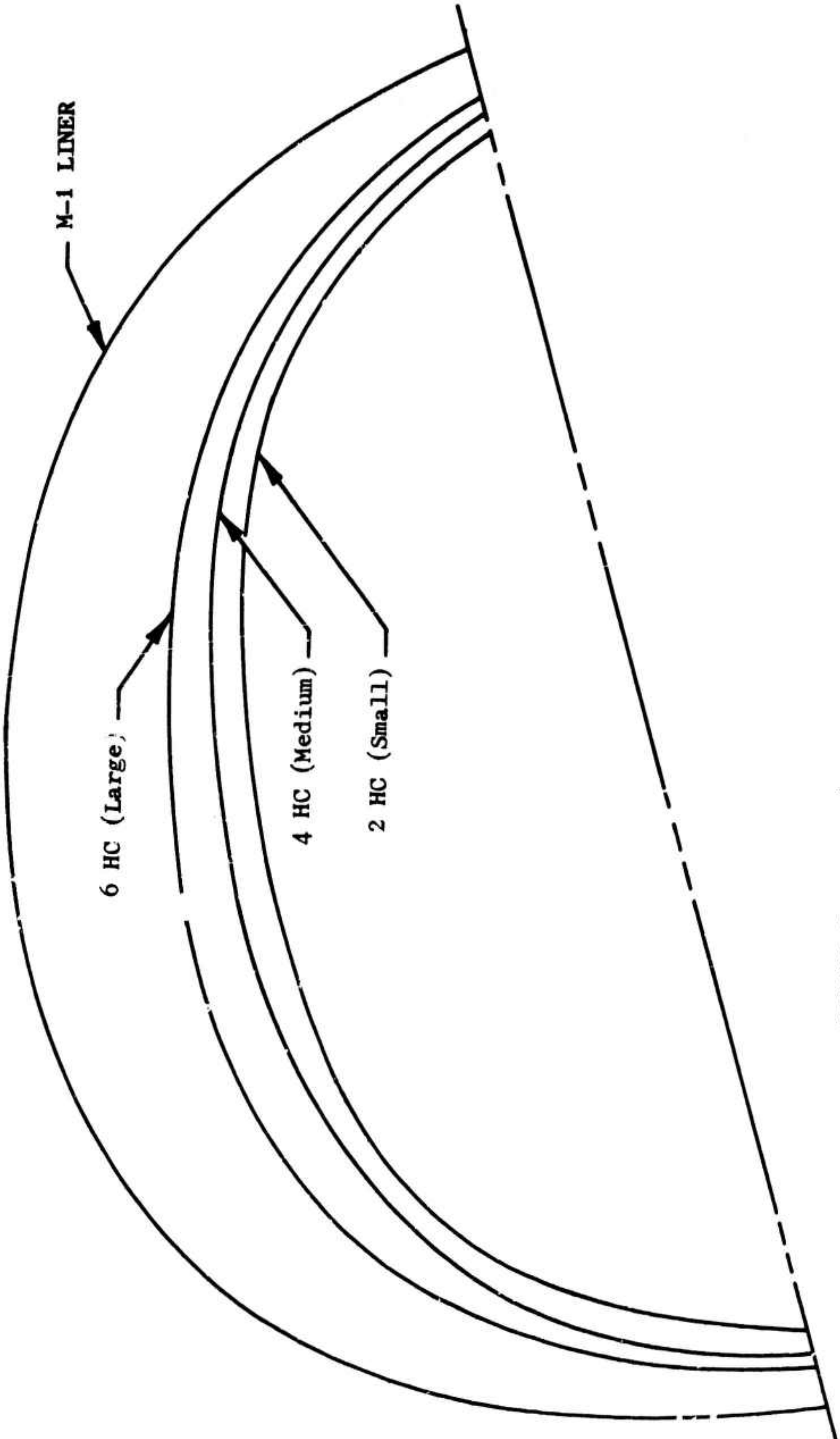


FIGURE 9 - LINER/HEADFORM CLEARANCES

solution for infantry helmet design. Since this study did not permit redesign of the helmet shell, the design solution was limited to the addition of local padding to absorb some of the shock.

Items 1) and 3) above describe the general impact requirements imposed on the suspension system. The requirements can be satisfied through design using either of the two basic suspension methods, the sling or conformal padding.

The projectile impact case was evaluated to determine if it imposed energy absorption design conditions on the suspension system.

For the purposes of this study, the impacting projectile was defined as a .22 caliber, Type II 17 grain (per MIL-P-46593) fragment simulating missile traveling at 1350 feet per second. The kinetic energy of such a projectile is determined by the equation.

$$KE = \frac{1}{2}\frac{w}{g}v^2$$

where $w = 17$ grains or 2.15×10^{-3} lb

$g = 32$ ft/sec/sec

$v = 1350$ ft/sec

$$KE = (2.15 \times 10^{-3})\ (1350)^2 \ /\ (2)\ (32)$$

$$KE = 61 \text{ ft-lb}$$

Impact energy levels of this magnitude when applied directly to any portion of the head by means of a low velocity, heavy pendulum almost always result in linear skull fractures. Gurdjian has determined that the average energy level required to produce fracture is 35 to 55 ft. lb. when tested by the forehead drop method.[3]

In this case of a high velocity, low mass projectile impact the result would certainly be skull penetration if permitted to impact the head directly. In the total helmet system design, the steel outer shell and the nylon liner act to dissipate the impact energy through the mechanical work of material deformation.

Assuming that the local deformation of the shell is limited to a deflection of .5 inches (the helmet offset dimension provided by the suspension system) then an estimate of the duration of the impact event can be made as follows:

$$t = \frac{2x}{v_p}$$

t = duration of impact in seconds

x = allowable deflection in feet $= \frac{.5}{12}$

v_p = projectile velocity in feet/sec. = 1350

$$t = \frac{2\ (.5)}{12(1350)}$$

t = .062 milliseconds

Because of the short duration of the impact event, it can be shown through an analysis of the spring-mass system comprised of the helmet shell, suspension system, and head that the helmet response is essentially independent of the suspension system design and that energy absorption and dissipation is initially confined to the helmet shell.

The conclusion drawn from the above discussion is that the projectile impact case can not be reduced to design requirements data to be used for the design of energy absorbing media in the suspension system.

For the purposes of this study, a heavy object impact case was derived as a design goal based on the work of Gurdjian in the design of protective athletic helmets.[4] The requirement as stated in the Requirement Guidelines Document, BW-240 appears below:

1) <u>Heavy Object Impact</u>

   A design goal of the suspension system shall be to provide an overall M-1 Helmet System protective index of 2 or greater. The protective index is defined as the ratio of the heavy object impact velocity with the helmet system in place to the impact velocity without the helmet for the same mean acceleration response of the impacted head.

Thus, if the unprotected head experiences a mean acceleration pulse of 100 g's when impacted by a 10-pound object traveling 8 ft/sec, the helmet system shall permit it to undergo an impact of 16 ft/sec by the same 10-pound object without causing the head to experience a mean acceleration greater than 100 g's. The design envelope of impact conditions expressed in terms of impact object weight (lbs), velocity (ft/sec), and kinetic energy (ft-lb) is presented in Figure 10.

2) Human Factors

The study shall consider the following physiological impact criteria:

a) Acceleration - Time Tolerance Curve - Figure 11

b) Maximum permitted onset acceleration rate: 20,000 g/sec

c) Maximum permitted energy to be absorbed by the head: 50 ft-lb

The program scope did not permit evaluation of the final system design against these requirements. It is recommended that future suspension system programs include contractor test and evaluation of end item performance against these requirements.

3. CONCEPT DEVELOPMENT

During this phase of the program, six different suspension system designs evolved. Consideration was given to both conformal suspension system and sling suspension system design approaches. Mockups of each of the six designs were fabricated. The six design approaches were then subjected to an engineering trade study to reduce the number of candidates to three. The resultant three design prototypes were then submitted to NLABS for evaluation and selection of the final design.

The design selected by NLABS identified as the Hook and Pile Suspension System (HPSS) during the program is fully described in Section 4 of this report.

This suspension system was chosen over the other two with high ratings for various reasons, including

1) minimum heat buildup
2) ruggedness
3) lower estimated cost
4) simplicity

The following paragraphs describe the functional and operational characteristics of the remaining five suspension system designs.

a. INFINITE ADJUSTMENT WEB

Figure 12a illustrates the configuration of this concept.

This concept is a sling-type suspension designed primarily to offer ease of size adjustment over the full range of head sizes. The unique feature is the two draw cords which provide independent adjustment of sweatband tension and suspension height.

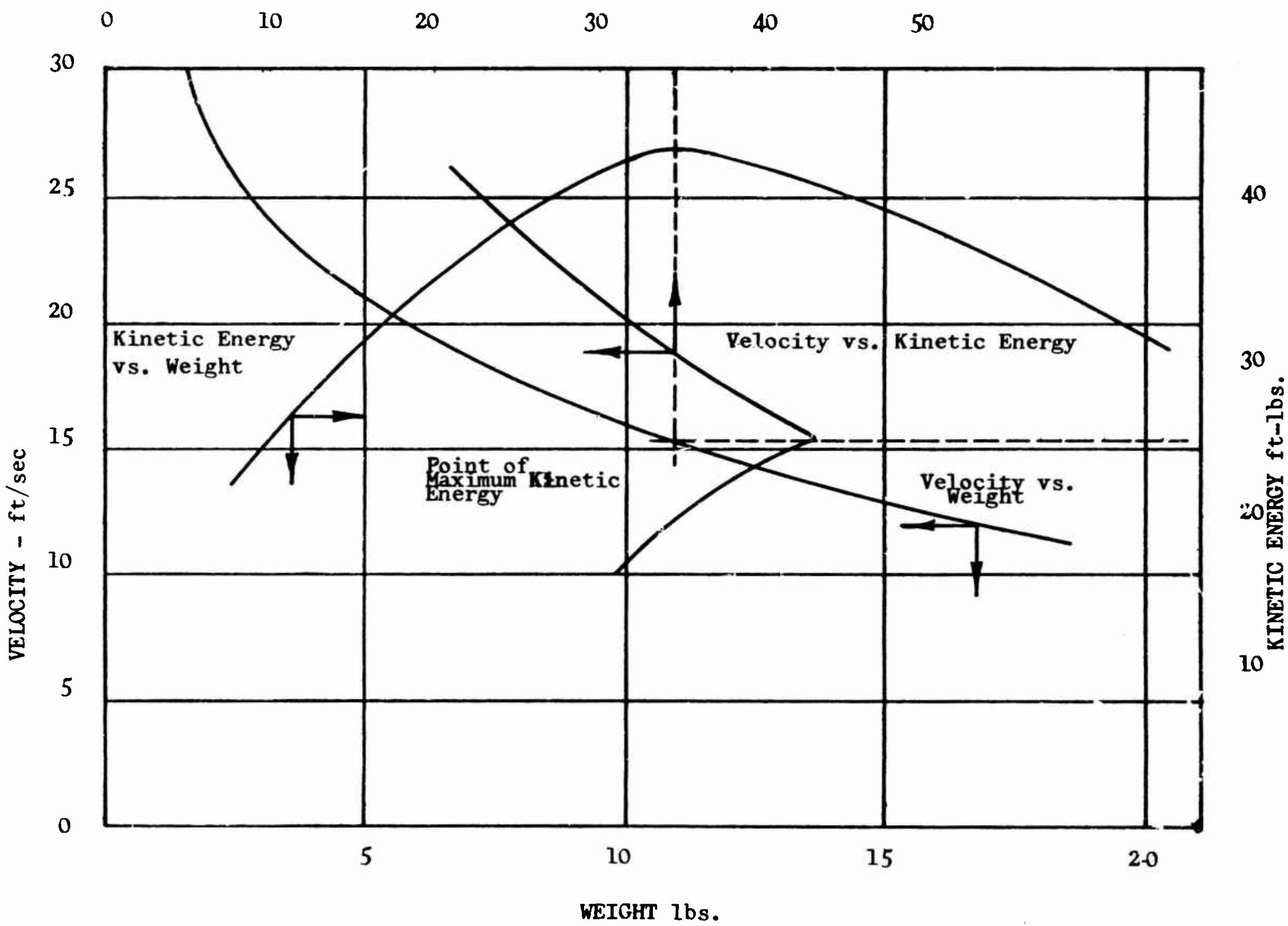


FIGURE 10 - HEAVY OBJECT INPACT DESIGN LIMIT ENVELOPE

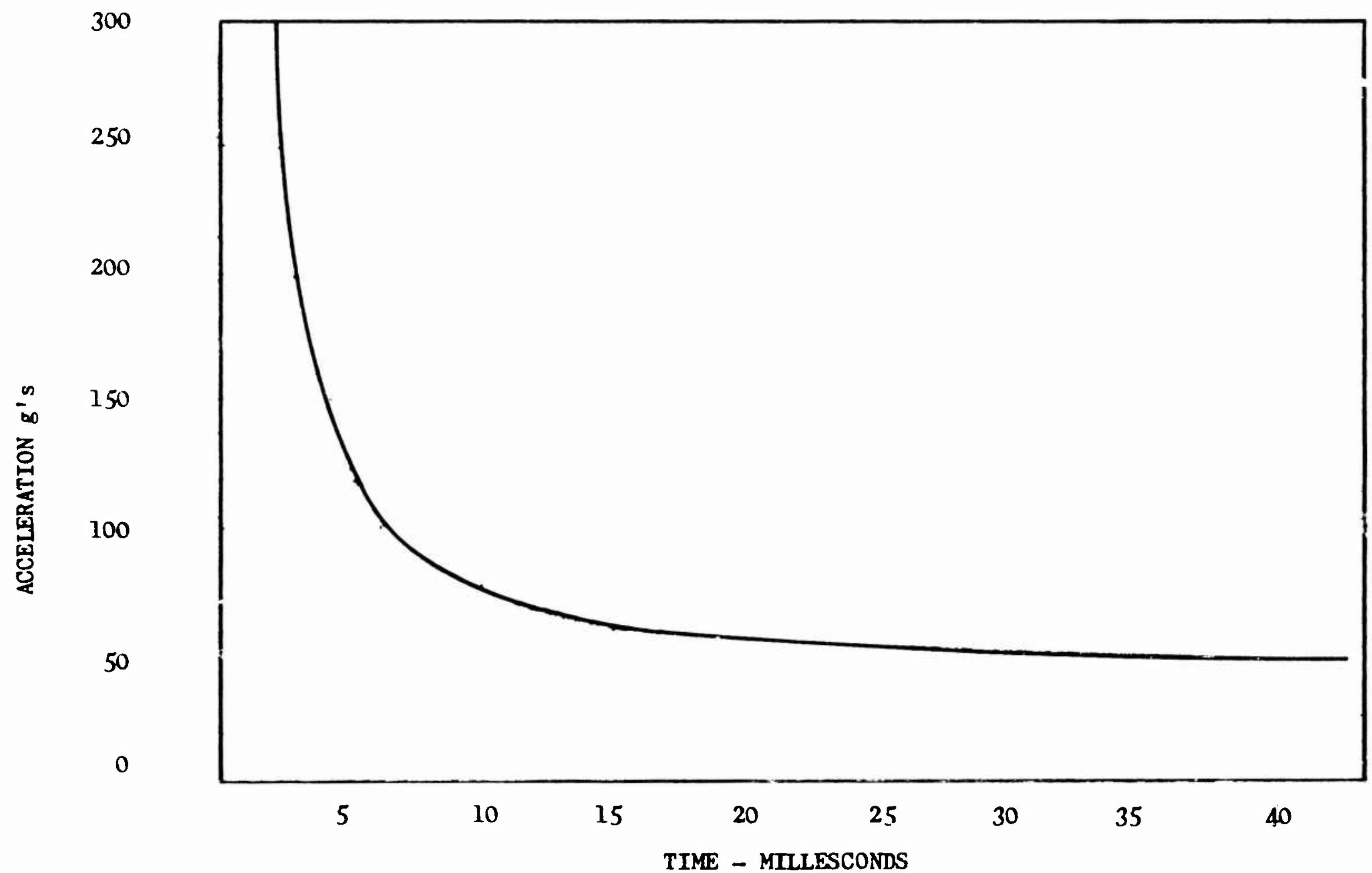


FIGURE 11 - HUMAN HEAD ACCELERATION - TIME TOLERANCE

a – INFINITE ADJUSTMENT WEB

b – SPIDER CONFORMAL

c – HYBRID CONFORMAL

FIGURE 12 – SUSPENSION SYSTEM CONCEPTS

The circumferential draw strings permit adjustment of the sweatband circumference to the exact head dimension while the helmet is worn in place as well as when it is doffed. Tightening of the draw strings permits adjustment of the suspension system compression to provide added holding power when conditions require it.

If the helmet is removed while the circumferential drawstrings are drawn up tight, then it is difficult to redon the helmet without first loosening the draw strings. However, with the sweatband elasticized as it is, it is not necessary to always tighten the draw cords for most non-combat situations.

The sagittal-coronal drawstrings provide helmet offset adjustment to ensure vertical positioning of the head within the helmet. The adjustment can be made with the helmet worn or doffed. Unlike the circumferential adjustment which is worn either drawn tight or released, the sagittal-coronal adjustment is made once and forgotten.

This concept provides good control of the tension forces in the sweatband strap. The spandex web which covers the entire head surface above the sweatband also provides a good frictional contact area to resist helmet motion. Observations made during the brief wear periods of this concept indicate good stability.

Closure of the forehead/nape aperture is accomplished with this concept by contouring the rear portion of the sweatband to contact the rear of the head below the normal sweatband level. A negative effect has been noted in the bunching of the sweatband material. This concept mounts to the M-1 liner using the existing suspension mounting hardware which is considered satisfactory for this use.

b. SPIDER CONFORMAL

Figure 12b illustrates the configuration of this concept.

This concept is a conformal type suspension designed to provide maximum impact protection within the volume limits of the M-1 liner. The concept is similar to the existing M-1 suspension design in the location and direction of the suspension members. However, instead of air space between the liner and the suspension webbing contacting the head, this concept incorporates high energy absorbing foam segments within this volume.

In the mockup construction, a commercial foam, blended of nitrile rubber and PVC plastic, was used as the energy absorbing media. The segments were cut from one inch thick foam, bonded to form the spider shape and then covered with nylon fabric. For proper operation, this concept requires that the spider fit flush with the inner surface of the liner and flush with the wearer's head. Variations in liner shape and head shapes suggest a number of potential problems in the development of this concept to achieve proper fit.

This concept provides about the same stability as the current M-1 helmet suspension system since the head contact geometry is about the same. However, it is doubtful that the same stability can be obtained without custom fitting of each spider to insure close contact with the wearer's head.

Conformal fitting of the spider pad is required to achieve:

1) Adequate load distribution of the helmet weight
2) Shock protection
3) Proper vertical positioning of head within the helmet

c. SPIDER/INFINITE ADJUSTMENT WEB

This concept uses the sizing adjustment technique of the first concept combined with the impact protection provisions of the second concept. The spider pad is provided only with large heads. For all smaller size heads, vertical adjustment is provided by the draw strings. A major benefit of this concept is the protection provided against bottoming of the shell on the head during impact.

d. HYBRID CONFORMAL

Figure 12c illustrates the configuration of this concept.

The concept is essentially a rigid conformal helmet worn within the M-1 helmet. The concept design was directed towards achieving good stability along with impact protection.

For the mockup construction, the major components were fabricated by vacuum forming high impact acrylic plastic into a female mold.

The shock absorbing vinyl foam was then bonded to the inner surface and brush-coated with a surface sealer.

This design requires a three or six-size schedule to adequately support the full range of head sizes. Even so, it is doubtful that the largest heads could be accommodated because of the dimensional limitation of the M-1 liner.

e. SHOELACE ADJUSTMENT SLING

This concept is a sling-type suspension designed to offer comfort and stability as well as full range adjustability. Stability is achieved through positive closure of the forehead-nape aperture by means of the integrated nape. The three basic components (front pad, crown pad, and nape pad) are padded for comfort and are laced together for sizing adjustment.

The results of the trade study are summarized in Table 3, 4, and 5. The concepts identified as the Infinite Adjustment Web, the Hook and Pile Suspension System, and the Shoelace Adjustment Sling were selected for presentation to NLABS for evaluation and selection of the final design.

Section 4 describes the Hook and Pile Suspension System selected by NLABS as the final design concept.

4. FINAL DESIGN CONCEPT

a. GENERAL DESCRIPTION

The Hook and Pile (Velcro Corp., New York, N. Y.) Suspension System consists of seven basic components as follows:

Suspension Mounting Bracket	2
Suspension Assembly - Left Side	1
Suspension Assembly - Right Side	1
Chin Strap Yoke	2
Chin Cup Assembly	1
Total	7

The left and right side suspension assemblies are attached together by means of hook and pile fabric to form the basic suspension unit. The unit attaches to each of the suspension mounting brackets by means of the eight nylon straps around the circumference. The chin

TABLE 3 - EVALUATION CHART

	Infinite Adjustment Web	Hook and Pile Suspension System	Spider Conformal	Hybrid Conformal	Shoelace Adjustment Sling	Spider/IAW	M - 1
1. **SIZING**							
a. One configuration fits all headsizes Yes = 3 No = 0	3	0	0	0	3	3	3
b. Sizing can be accomplished with the helmet in place on head Yes = 3 No = 0	3	0	0	0	0	3	0
c. Sizing can be accomplished with the helmet installed in liner (helmet doffed) Yes = 2 No = 0	2	2	2	0	2	2	2
d. Suspension can be tightened while worn in place Yes = 2 No = 0							
TOTAL	$\frac{2}{10}$	$\frac{2}{4}$	$\frac{0}{2}$	$\frac{0}{0}$	$\frac{2}{7}$	$\frac{2}{10}$	$\frac{0}{5}$
2. **COMFORT**							
a. Pressure points None = 3 Can be fixed = 2 Questionable = 0	3	2	3	0	2	3	3
b. Subjective opinion Max = 4	4	2	0	1	3	3	2
c. Minimum thermal problem Max = 3							
TOTAL	$\frac{2}{9}$	$\frac{1}{5}$	$\frac{0}{3}$	$\frac{0}{1}$	$\frac{1}{6}$	$\frac{0}{6}$	$\frac{2}{7}$

TABLE 3 - EVALUATION CHART (CONT'D)

	Infinite Adjustment Web	Hook and Pile Suspension System	Spider Conformal	Hybrid Conformal	Shoelace Adjustment Sling	Spider/IAW	M - 1
3. STABILITY							
a. Subjective opinion Max = 8	7	5	1	3	4	7	5
b. Problems noted from Mockup behavior-Redesign required Yes = 0 No = 2	2	0	0	2	0	0	0
TOTAL	9	5	1	5	4	7	5
4. OPERATIVE CHARACTERISTICS							
a. Size rank 1st = 3, 2nd = 2, 3rd = 1	3	1	0	0	2	3	1
b. No. of adjustments: Less than 8 = 1	1	0	1	1	1	1	0
c. Adjustment simplicity subjective Max = 4	4	3	4	3	2	4	2
d. Buckles eliminated Yes = 1 No = 0	1	1	0	1	0	1	0
e. Use M-1 mounting clips Yes = 1 No = 0	1	0	1	0	0	1	1
TOTAL	10	5	6	5	5	10	4

TABLE 3 - EVALUATION CHART (CONT'D)

	Infinite Adjustment Web	Hook and Pile Suspension System	Spider Conformal	Hybrid Conformal	Shoelace Adjustment Sling	Spider/IAW	M - 1
5. GENERAL DESIGN							
a. Ease of fabrication estimate Max = 4	2	3	1	0	2	1	4
b. Number of separable components 1 to 3 = 3 4 to 6 = 2 6 to 9 = 1	3	2	3	2	2	3	0
c. Launderability/reassembly Max = 3	3	2	3	3	1	2	2
TOTAL	7	7	7	5	5	6	6
6. DESIGN CONFIDENCE (Subjective)							
Best chance of satisfying requirements Max = 10	9	7	1	1	5	4	

TABLE 4 -- SUMMARY EVALUATION CHART - NO FACTORS

	Maximum Points	Infinite Adjustment Web	Hook and Pile Suspension System	Spider Conformal	Hybrid Conformal	Shoelace Adjustment Sling	Spider/IAW	M - 1
SIZING	10	10	4	2	0	7	10	5
COMFORT	10	9	5	3	1	6	6	7
STABILITY	10	9	5	1	5	4	7	5
OPERATIVE CHARACTERISTICS	10	10	5	6	5	5	10	4
GENERAL DESIGN	10	7	7	7	5	5	6	6
DESIGN CONFIDENCE	10	9	7	1	1	5	4	5
TOTAL	60	54	33	20	17	32	43	32
RANK		1	3	5	6	4	2	4

TABLE 5 - SUMMARY EVALUATION CHART - FACTORS APPLIED

	Estimated Weighting Factor	Maximum Points	Infinite Adjustment Web	Hook and Pile Suspension System	Spider Conformal	Hybrid Conformal	Shoelace Adjustment Sling	Spider/IAW	M - 1
SIZING	1.5	15	15	6	3	0	10.5	15	7.5
COMFORT	2.5	25	22.5	12.5	7.5	2.5	15	15	17.5
STABILITY	2.5	25	22.5	12.5	2.5	12.5	10	17.5	12.5
OPERATIVE CHARACTERISTICS	1	10	10	5	6	5	5	10	4
GENERAL DESIGN	1.5	15	10.5	10.5	10.5	7.5	7.5	9	9
DESIGN CONFIDENCE	1	10	9	7	1	1	5	4	5
TOTAL		100	89.5	53.5	30.5	28.5	53.0	70.5	55.5
RANK			1	4	6	7	5	2	3

strap yokes attach to the mounting brackets by means of the slots provided. The chin cup assembly attaches to the square ring on each chin strap yoke by means of the hook and pile tabs on the cup assembly.

Figures 13, 14, 15 and 16 provide various views of the HPSS.

b. ADJUSTMENT PROVISIONS

1) Helmet Height - Helmet height or offset is controlled by the two "over the head" hook and pile straps. This adjustment is made prior to installation of the suspension in the helmet.

2) Circumference - Circumference is controlled by the positioning of the eight nylon straps in the helmet mounting brackets and by adjustment of the forehead and nape hook and pile straps.

3) Fore and Aft - Fore and aft positioning of the head within the helmet can be controlled by the adjustment of the eight nylon straps.

4) Circumferential Tension - Circumferential tension can be controlled by adjustment of the rear (Nape) hook and pile strap.

5) Chin Strap Length - Chin strap length and tension is controlled by the combined adjustment of the chin strap yoke in the helmet mounting bracket and the chin cup assembly in the yoke square ring.

c. DESIGN FEATURES

1) Patterned Design - The left and right side suspension assemblies are fabricated from a buildup of materials cut from detail patterns. This approach permits the fabrication of circumferential and over-the-head elements which lie flat and remain in intimate contact with the head independent of head size. This concept is superior to designs which use straight lengths of web material stitched together to form the head cover. The straight lengths tend to twist and bunch up when they are curved around the head, resulting in poor fit and stability.

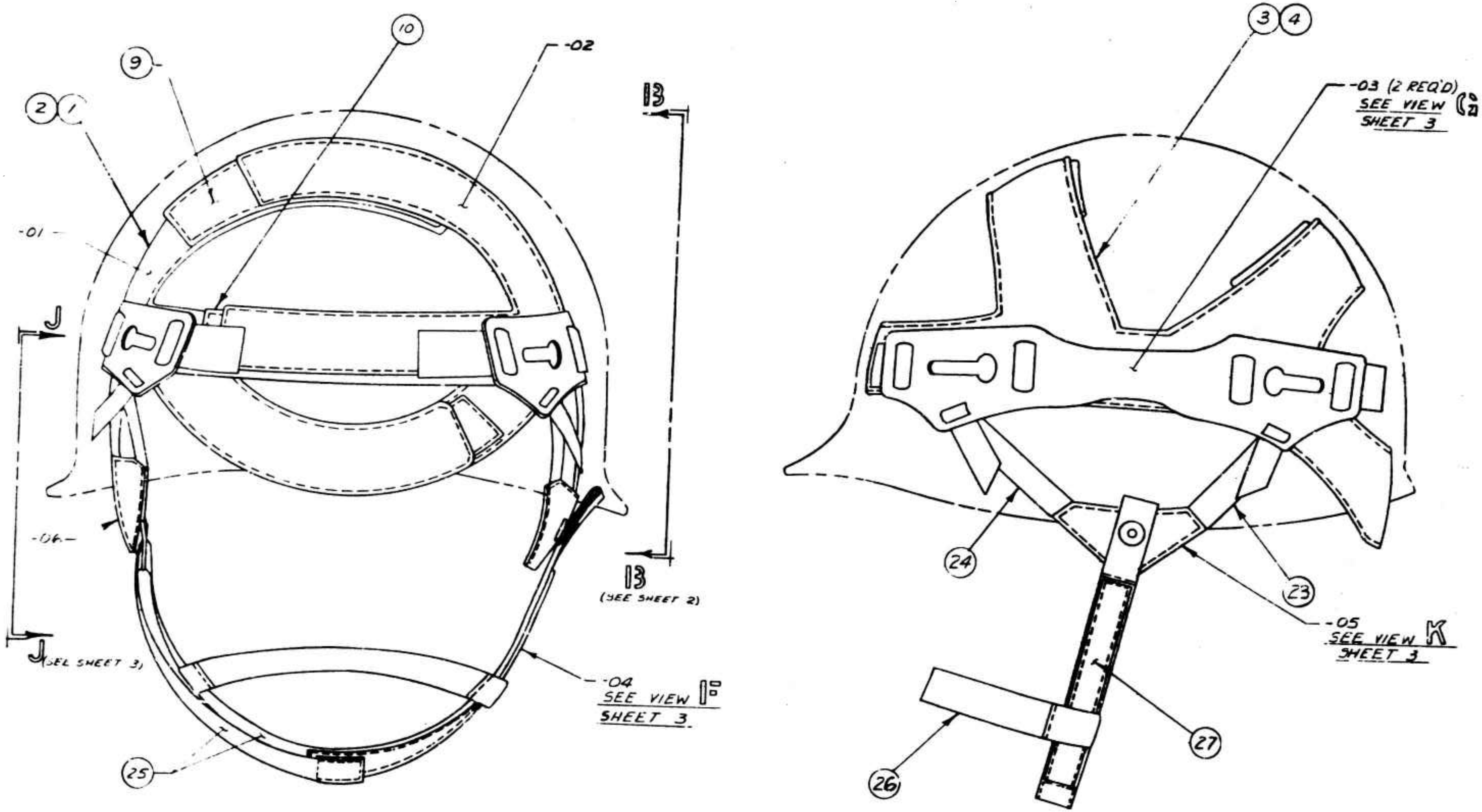


FIGURE 13 - HOOK AND PILE SUSPENSION SYSTEM

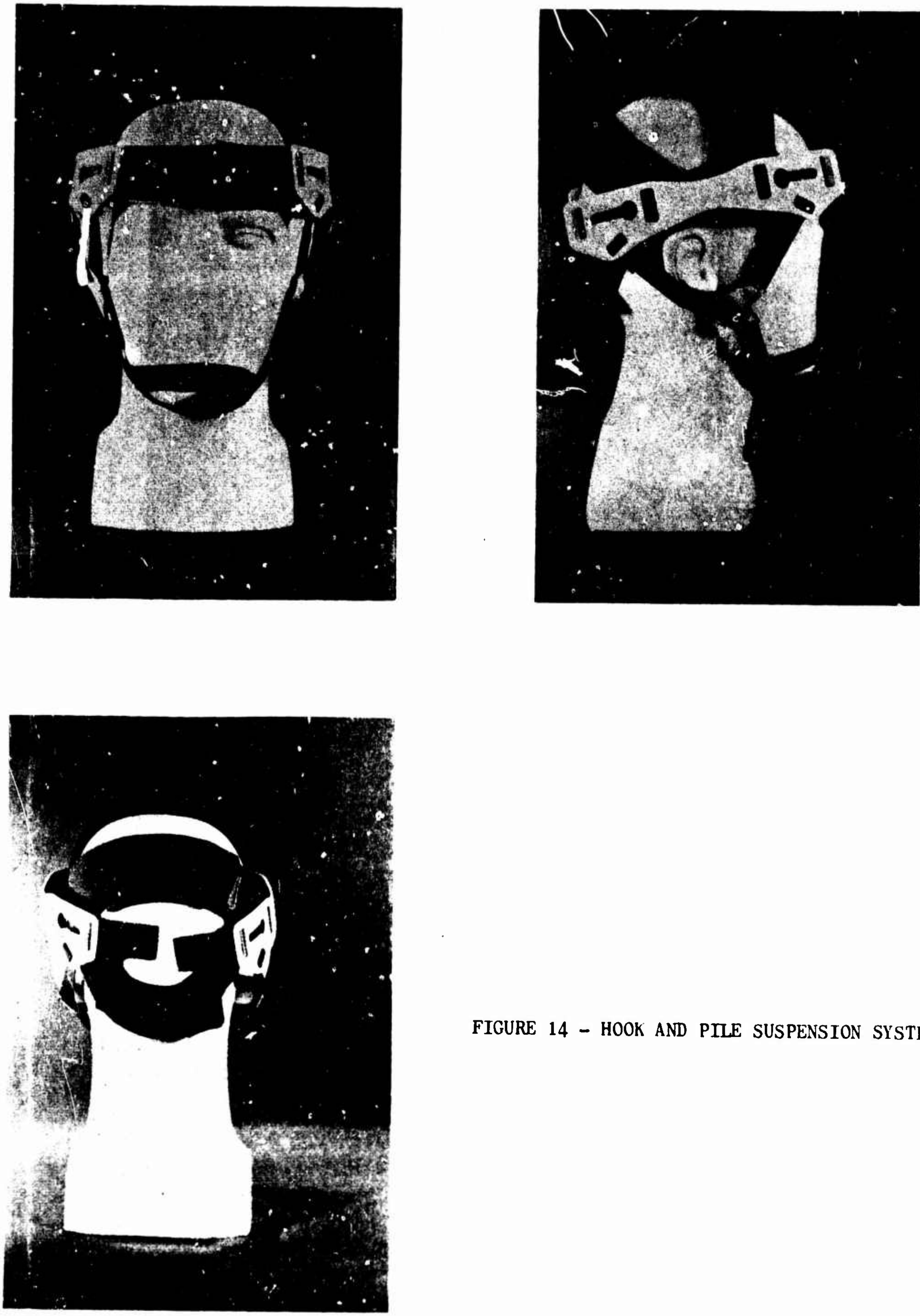


FIGURE 14 - HOOK AND PILE SUSPENSION SYSTEM

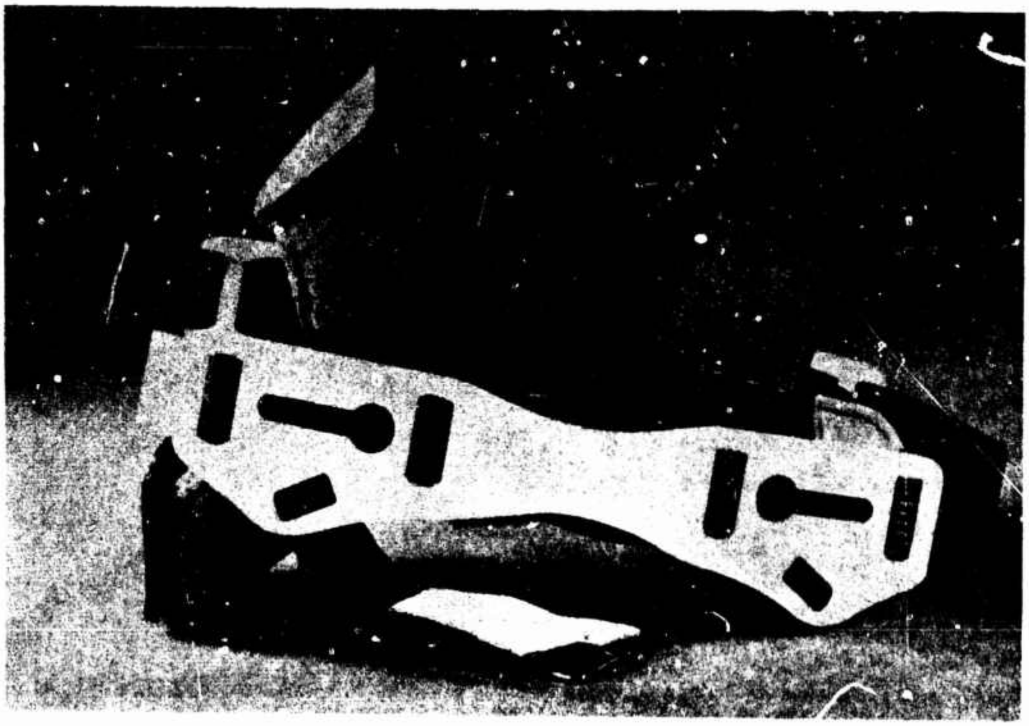


FIGURE 15 - HOOK AND PILE SUSPENSION SYSTEM

FIGURE 16 - HOOK AND PILE SUSPENSION SYSTEM

The present M-1 suspension system provides approximately 18 square inches of contact area to distribute the static load of the helmet when adjusted to fit the small size head. In comparison, the patterned design of the two over-the-head straps of the HPSS conforms to the shape of the head and provides a contact area of 23 square inches for the small size head. This greater contact area results in reduced pressure on the scalp and greater comfort. The increased contact area also contributes to improved stability by increasing the frictional surface area.

2) <u>Hook and Pile Sizing</u> - The left and right side suspension assemblies are joined together to form the basic suspension unit by means of hook and pile. The hook and pile used in this manner serves a dual purpose of first, joining the major elements together and second, providing a full range in head size adjustment from head circumferences less than 21 inches to greater than 24 inches. (over 99 percentile). In effect, the hook and pile permits the user to custom fit the basic suspension system to his head prior to installing it in the helmet.

3) <u>Integrated Adjustable Nape Strap</u> - The key to achieving stability in suspension system design is to make the diameter of the circumferential element smaller than the maximum diameter of the head and to locate the plane of this element below the plane of maximum head diameter. This objective is achieved in the HPSS by incorporating an integrated nape strap as a basic element of the suspension. This nape strap is unique in that it is adjustable with the helmet in place; it can be positioned below the inion without discomfort; and adjustment of the nape controls the tension in the circumferential element permitting tightening or loosening of the helmet without removal from the head.

5. RECOMMENDATIONS AND CONCLUSIONS

Fifty final design suspension systems have been delivered to the U. S. Army NLABS for field evaluation at Aberdeen, Maryland. The results of this evaluation have not been received and are not a subject of this report. However, initial acceptance by Army personnel exposed to the final design aside from the field evaluation, has been high. Improved comfort and stability are the features of the final design most often mentioned.

It is recommended that further effort be directed in the areas of a) Value Engineering and b) Engineering Testing.

a. Value Engineering

The final suspension system design approach followed in this study is ideally suited for a value engineering analysis. The methods and processes used in the fabrication of the 50 production units are satisfactory for the short run, but would be economically prohibitive in any larger scale procurement.

Cost reduction can be achieved through the following:

1) Use of pattern cutting dies

2) Development of alternate methods, processes and materials to eliminate sewing and to substitute heat sealing

3) Investigation of alternate methods to fabricate the plastic suspension mounting brackets

b. Engineering Testing

An engineering test program is recommended to provide quantitative data on the suspension system performance. Of importance are tests to measure the stability and impact attenuation characteristics of the suspension system.

The suspension system conceived and developed during this study represents the latest in the Army's efforts to provide the infantryman with a more comfortable, stable, and reliable suspension system for use with his M-1 helmet. This suspension system design effort, like others in the past, has had to deal with the limitations and restrictions imposed by the "traditional" steel shell and liner. Many of the suspension system design variables (helmet clearance, suspension mounting, helmet weight) are fixed by the existing shell.

A total system approach to the infantryman's helmet design is required to guarantee him the best possible battlefield protection along with the comfort and reliability necessary to ensure that he will be wearing his helmet when needed. The suspension and helmet shell must be designed together as part of one system to satisfy a given set of requirements. Hopefully when the time comes to approach this problem again, these requriements will include face protection and acoustic protection, both seriously lacking in the present M-1 Helmet design.

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